European Research Studies Journal
Volume XXIV, Special Issue 2, 2021

pp. 607-616

Analysis of Consumer Behavior through a Navigation System Inside Commercial Facilities

Submitted 24/03/21, 1st revision 19/04/21, 2nd revision 21/05/21, accepted 30/06/21

Michał Styła[1], Mariusz Kalita[2], Sylwester Bogacki[3],
Marta Cholewa-Wiktor[4]

Abstract:

Purpose: *The aim of this article is to develop complex IT and technological solution that allows locating and navigating inside buildings or closed facilities, not allowing the use of alternative technologies for navigation and localization. The system's purpose is to recognize people in two models (used interchangeably): I – the user has a receiving device, II – the user has no device.*
Design/Methodology/Approach: *The solution uses Bluetooth Low Energy technology version 4.2 and IEEE 802.15.4 protocol in accordance with the standards available on the radio equipment market. In order to increase the effectiveness of navigation, the system uses a Wi-Fi signal and data from sensors available in smartphones (gyroscope, accelerometer, magnetometer). In the context of localization, the system uses radio tomography techniques (Radio Tomographic Imaging – RTI). The method makes it possible to accurately determine the human position on the basis of changes in the strength of the recorded radio signals without a receiver such as a mobile phone.*
Findings: *The results of the research work indicate that created wireless navigation network using RTI techniques can significantly improve the accuracy of tracking users inside confined spaces.*
Practical Implications: *The system can be used to analyze the behavior and location of consumers in large scale stores, exhibition halls, museums and warehouses. The advantage of the solution is the ability to determine the location of people without the need for a smartphone with dedicated application.*
Originality/Value: *The innovativeness of the introduced solutions manifests itself in may dimensions. In the context of the innovation of the solution is manifested, among others in the hybrid use of radio technologies for navigation in confined spaces. From the perspective of process innovation, it manifests itself in new possibilities for monitoring human flows in closed facilities, thus providing a number of analytical dara for the facility manager.*

Keywords: *Navigation system, consumer behavior, radio tomography imaging, bluetooth.*
JEL codes: *C61, C88, M30.*
Paper type: *Research article.*

[1]*Corresponding author, CBRTI Sp. z o.o., Rzeszów, Poland, e-mail: michal.styla@cbrti.pl*
[2]*University of Economics and Innovation in Lublin, Lublin, Poland, e-mail: mariusz.kalita@wsei.lublin.pl*
[3]*Same as in 2, e-mail: sylwester.bogacki@wsei.lublin.pl*
[4]*Faculty of Management, Lublin University of Technology, Lublin, Poland, e-mail: m.cholewa@pollub.pl*

1. Introduction

Currently, more and more people have to deal with movement in buildings with very large surface area. The need to visit them appears almost constantly, whether it is when visiting a hospital / office, shopping in a shopping centre or participating in trade fairs. Due to the increasingly expanding infrastructure of many institutions, shopping centres and other public places such as stations, airports, and hence increasing problems in navigating such facilities, the need to implement navigation inside buildings is increasing (Zafari, Gkelias, and Leung, 2019, Xiong and Jamieson, 2013).

A common problem in commercial facilities is the difficulty in finding the shop, stand, and the lack of advanced search and sorting in stationary maps. On the part of managers and tenderers, there is no data to determine the prices of a given space, access to modern marketing channels, optimal communication with the client (Liu *et al.*, 2007, Altini *et al.*, 2010).

Technological advances in recent years have resulted in an exponential growth in localization technologies. The most common positioning systems that have been commercialized are associated primarily with the Global Positioning System (GPS) (El-Rabbany, 2006). However, in confined spaces, inside buildings, GPS signals cannot be received. Navigation systems are extremely useful, and the possibilities they provide seem to be irreplaceable in today's world. Particularly useful, in the scale of the entire society, is the ability to move around and reach your destination in areas completely unknown to the user of the system. It is impossible not to extrapolate its usefulness to indoor conditions.

Problems with establishing and maintaining a GPS signal clearly suggest that this technology can have major problems with serving as indoor navigation. Signals used by other locating technologies developed are also often insufficient in this case. Systems that rely no the use of cellular communication signals and identify nearby Wi-Fi access points allows to maintain a constant and stable connection, but do not provide sufficient accuracy, which makes it impossible to distinguish individual rooms in a building. GPS-based systems can achieve the accuracy needed to locate users, but they cannot operate indoors due to signal interference from walls, floors, furniture, and other objects. Due to these limitations, navigation inside buildings is mostly still based on reading plans for individual buildings.

Recently, many different methods and techniques have been developed for indoor location and navigation services. These techniques are mainly based on Radio Frequency (RF) operation and Received Signal Strength Indication (RSSI) analysis (Yang, Zhou, and Liu, 2013). The accuracy achieved with such systems is usually low, mainly due to the variability of the RSSI in time. No wonder, then, that various organizations, both enterprises and research units, tried to develop a solution that would allow for precise navigation inside building and would be devoid of disadvantages of these systems. The research carried out during the preparation of the work aimed at developing methods and tools that would efficiently locate the user on the basis of BLE signals, and at the same time would be easy to implement in buildings. As part of this work, a technological analysis was performed and a navigation system with the use of Beacon systems was developed (Rymarczyk *et al.*, 2020).

Beacons are electronic transmitters that use BLE to transmit a signal to nearby electronic devices. Beacons allows to perform many activities and interact with those in their vicinity. Beacons use Bluetooth 4.0 technology or higher to transmit a universal, unique identifier received by an application or operating system designed for this task. The identifier sent together with the data can be used to determine the physical location of the device.

The designed system uses not only Bluetooth for operation. It also uses the IEEE 802.15.4 and Wi-Fi protocol depending on the device configuration and the operation performed (Haeberlen *et al.*, 2004; Krishnan *et al.*, 2004). In such configuration, the system is able to replace disadvantages of another technology, the advantages of another by creating a flexible, universal navigation platform. Three technologies closed within one system serve both navigation using the so-called beacons and radio tomography imaging, the task of which is to significantly increase localization accuracy in selected parts of the building (Castro *et al*., 2001; Youssef and Agrawala, 2007; Xiao *et al.*, 2013).

2. Methodology

2.1 Navigation with Usage of User's Device

In the case of navigation based on communication with the user's device (the previously mentioned model I), the designed system uses the previously mentioned beacon, namely beacons made on the basis of Bluetooth Low Energy 4.2 technology. Using one of the flagship Bluetooth functionalities, i.e., advertising devices emit UUID (universally unique identifier) and some other additional information for housekeeping purposes. Based on the analysis of the received signal strength (RSSI) from individual beacons using an application on a mobile device (smartphone, tablet), it is possible to determine the distance from a given beacon, and staying within the range of at least three beacons, using appropriate triangulation algorithms and downloading relevant data form the server, determine the location of the device.

Based on the above data, it is possible to initiate appropriate actions on the customer's device e.g., displaying an appropriate marketing message, promotion code, more information about the nearby objects /environment or anything else that may be useful depends on the type of area. At the same time, the server receives valuable information about the location of devices (their owner), the time spent in a given zone or in the vicinity of a many applications. The combination of beacon infrastructure in a given area with an application dedicated to customers opens up an endless range of possibilities that will improve business efficiency.

A graph can be defined for each map to create navigation in the application. Graph vertices can be assigned to shops, rooms, stairs, elevator or special objects such as ATM. The coordinates of the vertices of the graph are given in meters form the zero point of the map. When saving the graph, the system automatically calculates the weight for each edge of the graph based on the coordinates of the vertices. In this case, the value given in the weight is the distance in meters between two graph vertices between which the edge is located, in other words, it is the length of the selected edge. When executing the request to calculate the shortest path to the selected point of the market, the start point is determined first. For this purpose, the user's location in the gallery is collected based on the beacons. This location is added to the graph as another vertex and connected to the nearest vertex. Still, in order to find the shortest path between two vertices of the graph, the Dijkstra algorithm is used.

The Dijkstra algorithm is used to determine the smallest distance form a fixed vertex *s* to all others in the directed graph, however, unlike the Ford-Bellman algorithm, the input graph cannot contain edges with negative weights. The algorithm remembers a set of *Q* vertices for which the shortest paths have not yet been calculated, and the vector *D [i]* of distances from *s* to *i*. Initially, the set *Q* contains all the vertices and the vector *D* is the first row of the edge weight matrix *A*.

The algorithm is as follows:

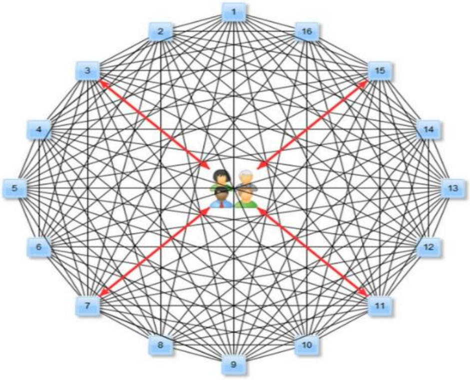
- Until the set *Q* is not empty, perform:
- Take the vertex *v* with the smallest value *D [v]* from the set *Q* and remove it from the set,
- For each successor and vertex v perform the path relaxation, i.e. check whether formula (1), i.e. whether the current estimate of the distance to the vertex I is greater than the estimate of the distance to the vertex *v* plus edge weight (*v*, *i*). If so, update the estimate *D [i]* assigning it to the right side of the inequality (i.e. the lover value).

$$D[i] > D[v] + A\ [v,i] \quad (1)$$

2.2 Navigation without Usage of User's Device

In the case of imaging with the help of radio tomography, not only Bluetooth 4.2 technology was used, but also the 802.15.4 (XBee) and Wi-Fi protocol. During the work on the system, several measurement sequences were tested in terms of measurement stability and speed both int the case of Bluetooth devices and Xbee modules. In order to obtain individual matrix measurements, it is necessary to communicate between all network nodes. In the case of a 16 – sensor, we get 240 values. The resulting measurement grid is visualized in Figure 1.

Figure 1. *All projection angles that make up the measurement grid in radio tomography*



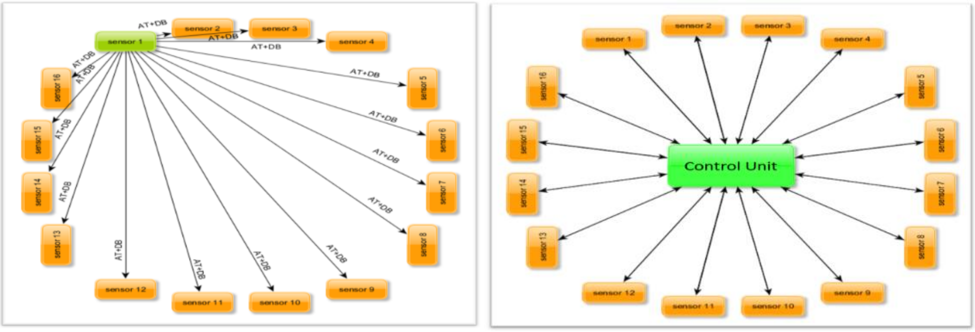
Source: *Own creation.*

The measurement is performed sequentially, i.e., one transmits, the other devices receive the data by measuring the strength of the transmission signal. Then, after taking the measurement, they send the information back to the transmitting device about the signal value. This process is repeated for each of the electrodes. The signal strength is checked using the AT + DB remote command. After receiving such a command, the devices send back information about the signal strength of the last transfer. The measuring sequence for obtaining a single row of the matrix is shown in Figure 2a.

Supervision over the measurement process is performed by the central unit, which is a device supervising the measurement process, sequentially sends commands to individual devices, initiating the measurement process in their code. After the probe completes the measurement process, the collected data is sent back to the monitoring device, where the data is further completed and sent via the Internet to the server. An additional function of the central device is a kind of tunnel through which information is transferred from the server regarding the need to change the configuration. The relationships of the radio probes and the central control unit are shown in Figure 2b.

In the research, the transmission model was used. The measured values were the received signal strength. Measurements were taken in the room and the phantoms were people. The antennas were suspended at a height of 140 centimeters. The image resolution was set to 63x65 pixels. It is also worth adding that the measuring equipment automatically selected the best channel – the frequency band in which the network was transmitting the signal. The model of the test room is presented in Figure 3.

Figure 2. *Measurement sequences for individual stages of data acquisition: (a) – communication diagram in the measurement process (b) – diagram of communication between the central unit and the probes*



(a) **(b)**

Source: *Own creation.*

An influence matrix was used which was build on the basis of the Fresnel zone. Due to the influence of objects inside the zone on communication, radio tomography allows for the detection of objects – image reconstruction. In the case of measurements made in the research room, the Tikhonov regularization was used to solve the inverse problem. The regularization parameter with the value of λ = 19000 was arbitrarily adopted. Then the inverse matrix was determined and the image vector was created on its basis. As in the case of the tests carried out on the wheel, a convolution filter was used – based on the Marra wavelet. On the other hand, the resulting image matrix was set at 60% of the maximum value. Depending on the configuration, there were one or two people in the room. A single object was well recognized, especially when it was away form antennas – the closer it was, the greater the imperfections in the reconstructed image. Additionally, it is worth noting that when people were close to each other, they left the reconstruction as one large object. This is due to small number of measuring points. Therefore, the spatial resolution is low.

To obtain the reconstruction, we need to solve simple equation:

$$J\,e = m \tag{2}$$

where J is a sensitivity matrix, m is the measurement vector and e is the vector containing all the finite elements of the computational mesh. Each row of sensitivity matrix J consist of elements which value correspond to the sensitivity of given pixel to the measurement for given pair of probes. We index each row of sensitivity matrix to the all combinations of pair of probes. In order to find reconstruction with on the elements from vector e, we need to fine and inverse of matrix J.

$$J^{-1}m = e \tag{3}$$

The difficulty of the problem comes from the fact that in almost all cases, the matrix J is non-square, thus the problem is ill-conditioned (Tikhonov, 1998). For example, the size of vector m in the case of 16 probes is 256, while the size of vector e can be much larger than 1000. We use a Tikhonov regularization method to find such inverse.

The sensitivity matrix is calculated with the assumption that the significant area between two probes that can contribute to the decrease of the RSSI has a shape of ellipsoid.

The calculation of the inverse of the J matrix is CPU computationally intensive, but once calculated it can be stored for later use, and the calculation of the reconstruction for typical problems are of order of 1-2 ms per reconstruction.

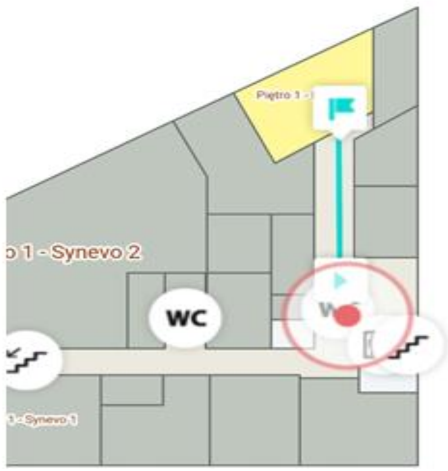
2.3 The Algorithm

1. Loading the background matrix and the measurement matrix.
2. Determination of the apparent distance d_{poz}, compliant with the results obtained from the probe filled with water. It was also assumed that the speed of sound in water is $1400\,\frac{\mathrm{m}}{\mathrm{s}}\,(V_w)$. Formula: $d_{poz} = M_B * V_w$, where M_B is the background matrix.
3. Calculation of the speed V_{wyz} based on the formula: $V_{wyz} = d_{poz}/M_m$, where M_m is the measurement matrix.
4. Convert the resulting matrix containing velocities into a vector.
5. Programming the measurements when the speed of sound exceeded $1400\,\frac{\mathrm{m}}{\mathrm{s}}$, it was set at a constant value of $1620\,\frac{\mathrm{m}}{\mathrm{s}}$s.
6. Exposing the differences between the velocities of sound in the tested media by increasing the obtained speeds to the tenth power.
7. Using tSVD with a constant cut-off value set to 90. About 32% of singular values were used for the reconstruction.
8. From the obtained results, the positive results were rejected and assigned the value to zero.
9. The other negative values have been changed to the opposite sign.
10. Filtering with a Marr wavelet with a size of 9×9 pixels and a standard deviation of 4 was performed.
11. Progression at the level of 45% from the maximum of the obtained values.
12. Visualization only within the field of view of the measuring system.
13. Standardized to the speed range of $330\,\frac{\mathrm{m}}{\mathrm{s}} - 1400\,\frac{\mathrm{m}}{\mathrm{s}}$.

3. Results

The results of the operation of individual components of the navigation system i.e., the beacon network and radio tomography, should be presented.

Figure 3. *An example of the operation of the navigation on the test building: (a) – The application mapping the route and marking start and end points, (b) – The system updates the user's position*



(a) **(b)**

Source: *Own creation.*

The mobile application helps us navigate to a selected, defined place in the building. In order to set the route, select the appropriate place, e.g., a room, and click on it. In the application, the active room will be highlighted with a color and a panel with its name and the "Navigate from my location" button will appear in the upper part of the application. An example of subsystem operation is presented in Figure 3.

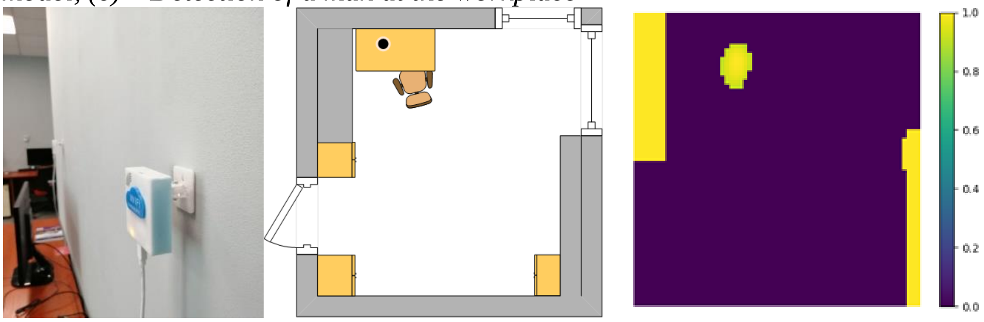
If the user is in a special room, the application displays a view showing the result of image reconstruction with the use of devices placed in it. For this purpose, sixteen antennas were placed in the research room, which is used on a daily basis as a laboratory. An examples of subsystem operation is presented in Figure 4 and Figure 5.

Figure 4. *Data acquisition and analysis by the radio tomography system*

Reconstructions Entries				
Creation Time	Place	Reconstruction	Device State	Image
2019-12-09 15:52:42+01:00	Data Science in Applications Room 001	[[240, 81, 88, 86, 85, 83, 85, 88, 90, 75, 77, 71, 77, 65, 71, 71], [82, 240, 69, 78, 78, 76, 78, 68, 74, 79, 77, 0, 255, 74, 0, 255], [88, 70, 240, 76, 75, 69, 79, 77, 75, 89, 76, 74, 86, 68, 80, 89], [255, 73, 255, 240, 255, 255, 255, 76, 82, 83, 255, 70, 255, 255, 67, 255], [255, 255, 74, 77, 240, 255, 255, 73, 255, 255, 255, 76, 70, 89, 79, 255], [82, 70, 67, 83, 76, 240, 90, 68, 70, 74, 71, 73, 70, 64, 76, 79], [255, 255, 255, 255, 255, 255, 240, 62, 71, 255, 92, 255, 67, 255, 73, 77], [83, 68, 75, 76, 70, 69, 64, 240, 79, 93, 81, 82, 80, 67, 91, 95], [255, 77, 75, 81, 82, 67, 70, 80, 240, 91, 255, 91, 79, 255, 86, 255], [255, 80, 86, 78, 86, 76, 78, 255, 80, 240, 83, 255, 81, 73, 255, 79], [255, 76, 76, 0, 79, 72, 0, 0, 0, 0, 240, 0, 0, 0, 0, 0], [0, 81, 0, 0, 255, 0, 0, 0, 0, 0, 240, 0, 0, 0, 0], [82, 80, 80, 67, 71, 74, 72, 81, 81, 78, 87, 75, 240, 69, 87, 88], [255, 255, 65, 255, 255, 255, 63, 255, 255, 255, 255, 255, 255, 240, 255, 255], [87, 77, 79, 67, 69, 80, 71, 87, 96, 79, 85, 86, 84, 75, 240, 85], [69, 83, 255, 255, 76, 255, 255, 255, 78, 76, 75, 66, 84, 67, 80, 240]]	[True, True, True, True, True, True, True, True, True, True, True, True, True, True, True, True]	
2019-12-09 15:52:25+01:00	Data Science in Applications Room 001	[[240, 81, 88, 86, 85, 83, 85, 88, 90, 75, 77, 71, 77, 65, 71, 71], [82, 240, 69, 78, 78, 76, 78, 68, 74, 79, 77, 0, 255, 74, 0, 255], [88, 70, 240, 75, 74, 69, 78, 78, 75, 89, 76, 74, 84, 69, 80, 90], [255, 73, 255, 240, 255, 255, 255, 76, 82, 83, 255, 70, 255, 255, 67, 255], [255, 255, 74, 77, 240, 255, 255, 73, 255, 255, 255, 76, 70, 89, 79, 255], [81, 70, 67, 82, 75, 240, 88, 68, 70, 73, 71, 73, 70, 65, 76, 81], [255, 255, 255, 255, 255, 255, 240, 62, 71, 255, 92, 255, 67, 255, 73, 77], [83, 68, 75, 76, 70, 69, 64, 240, 79, 93, 81, 82, 80, 67, 91, 95], [255, 77, 75, 81, 82, 67, 70, 80, 240, 91, 255, 91, 79, 255, 86, 255], [255, 80, 86, 78, 86, 76, 78, 255, 80, 240, 83, 255, 81, 73, 255, 79], [255, 76, 76, 0, 79, 72, 0, 0, 0, 0, 240, 0, 0, 0, 0, 0], [0, 81, 0, 0, 255, 0, 0, 0, 0, 0, 240, 0, 0, 0, 0], [82, 80, 80, 67, 71, 74, 72, 81, 81, 78, 87, 75, 240, 69, 87, 88], [255, 255, 65, 255, 255, 255, 63, 255, 255, 255, 255, 255, 255, 240, 255, 255], [87, 77, 79, 67, 69, 80, 71, 87, 96, 79, 85, 86, 84, 75, 240, 85], [69, 83, 255, 255, 76, 255, 255, 255, 78, 76, 75, 66, 84, 67, 80, 240]]	[True, True, True, True, True, True, True, True, True, True, True, True, True, True, True, True]	
2019-12-09 15:52:08+01:00	Data Science in Applications Room 001	[[240, 81, 87, 86, 86, 83, 83, 88, 91, 75, 77, 71, 78, 66, 71, 71], [82, 240, 69, 78, 78, 76, 78, 68, 74, 79, 77, 0, 255, 74, 0, 255], [88, 70, 240, 75, 74, 69, 79, 77, 74, 94, 76, 74, 84, 69, 80, 88], [255, 73, 255, 240, 255, 255, 255, 76, 82, 83, 255, 70, 255, 255, 67, 255], [255, 255, 74, 77, 240, 255, 255, 73, 255, 255, 255, 76, 70, 89, 79, 255], [80, 70, 68, 86, 76, 240, 87, 68, 69, 73, 71, 71, 70, 65, 76, 79], [255, 255, 255, 255, 255, 255, 240, 62, 71, 255, 92, 255, 67, 255, 73, 77], [83, 68, 75, 76, 70, 69, 64, 240, 79, 93, 81, 82, 80, 67, 91, 95], [255, 77, 75, 81, 82, 67, 70, 80, 240, 91, 255, 91, 79, 255, 86, 255], [255, 80, 86, 78, 86, 76, 78, 255, 80, 240, 83, 255, 81, 73, 255, 79], [255, 76, 76, 0, 79, 72, 0, 0, 0, 0, 240, 0, 0, 0, 0, 0], [0, 81, 0, 0, 255, 0, 0, 0, 0, 0, 240, 0, 0, 0, 0], [82, 80, 80, 67, 71, 74, 72, 81, 81, 78, 87, 75, 240, 69, 87, 88], [255, 255, 65, 255, 255, 255, 63, 255, 255, 255, 255, 255, 255, 240, 255, 255], [87, 77, 79, 67, 69, 80, 71, 87, 96, 79, 85, 86, 84, 75, 240, 85], [69, 83, 255, 255, 76, 255, 255, 255, 78, 76, 75, 66, 84, 67, 80, 240]]	[True, True, True, True, True, True, True, True, True, True, True, True, True, True, True, True]	

Source: *Own creation.*

Figure 5. *Results of work on navigating without using the user's device: (a) – Probes placed in housings and placed on the walls, (b) – Illustrative 2D test room model, (c) – Detection of a man at the workplace*



(a) **(b)** **(c)**

Source: *Own creation.*

4. Conclusions

Currently, there are several entities operating on the indoor navigation market. However, it is impossible to distinguish one that could be considered the leader of the entire industry. This is partly due to the still early stage of development of this market branch, which is reflected in the rather incidental nature of the implementations. In addition, there is little visible commitment of actors to globalization. Rather, they tend to act locally according to their geographic location.

There is also a lack of standardization in the application area on the market. None of the entities involved in the implementation of navigation systems has a universal application that could be used with each implementation. The development of electronics and the ubiquitous miniaturization of transmitting systems means that the demand for solutions in the area of microlocation will increase. The application and system components developed in the course of less work can be implemented in many branches of the economy, and the target recipient of the product does not have to be only large-area shopping centers.

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